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Payload Analysis for Space Shuttle Applications (Study 2.2) Final Report

Volume IV: Executive Summary

Prepared by
ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

15 October 1972

Prepared for OFFICE OF SPACE SCIENCE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

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Systems Engineering Operations
THE AEROSPACE CORPORATION

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Prepared by Advanced Vehicle Systems Directorate

Approved

Ernest I. Pritchard

E. I. Pritchard
NASA Study 2.2 Director
Advanced Vehicle Systems Directorate

L. R. Sitney

L. R. Sitney, Associate Group Director
Advanced Vehicle Systems Directorate
Systems Planning Division

Samuel M. Tennant

S. M. Tennant, Associate General Manager
Systems Planning Division
Systems Engineering Operations

FOREWORD

From 1 October 1971 through 31 August 1972, The Aerospace Corporation performed the Payload Analysis for Space Shuttle Applications under the direction of Dr. Rodney W. Johnson, OSS, NASA Headquarters. The Reusable Payload Specification effort is reported in Volume I. Space Shuttle payload design guidelines, procedures, and requirements were developed for use by OSS and OA in defining payloads for Shuttle/Tug.

The activity accomplished on the Payload Data Book is described in Volume II. Descriptions and technical data on each NASA payload for the June 1972 NASA mission model are documented.

The Payload System Operations effort is reported in Volume III. Space Shuttle payload programs were analyzed using the HEAO, communications satellite, Space Tug, and sortie missions for solar observations as typical examples. The data base and analysis depicted in Figure 1, which were used to derive the Shuttle payload design guidelines and the supporting rationale, include a broad range of payload and Shuttle/upper stage data covering costs, design, performance, and integrated payload/Shuttle effects. Shuttle payload program guidelines were developed on the basis of NASA study efforts available for this analysis (see Figure 1). In addition, the data from the Aerospace design, cost, and operations analyses reported in Volume III were utilized in generating the guidelines (see Figure 1).

1. INTRODUCTION

New ways to accomplish planned space program objectives have been studied in light of new concepts and techniques made possible by the Space Shuttle. Solar observation in a Shuttle sortie mode was studied. Automated and man-tended modes of operation for observatories were studied for the HEAO satellite program. Automated on-orbit maintenance and ground refurbishment modes were analyzed and compared (see Figures 2, 3, and 4). The design analyses accomplished for HEAO-C and the solar observatory program are directly applicable to OSS as Shuttle payload concept tradeoff studies.

An automated communications satellite (see Figure 5) and Tug were studied in the context of OA demonstration programs. The Tracking and Data Relay (TDRS) satellite program and the System Test Satellite program were used as examples of these programs. The results of this design analysis work are applicable to OA as concept tradeoff studies for the TDRS and System Test Satellite programs.

The results of the above design/analysis work; reports on the General Dynamics RAM, the Lockheed Payload Effects, the McDonnell Douglas SOAR, the Martin Marietta Payloads Implementation at Shuttle Launching Site; and the Aerospace Corporation Space Shuttle Mission and Payload Capture Analysis were used to build on the Lockheed Shuttle payload design guidelines. A composite Shuttle Payload Design Guideline document extending the LMSC study was generated as Volume I of this report. The Shuttle definition is consistent with current Level I Shuttle requirements (Ref. 3) and the description in the MSC Payload Accommodation document (Ref. 2). The Tug is the baseline described in the MSFC Tug report (Ref. 4).

A related effort resulted in a revised NASA Payload Data Book, Volume II of this report. The best available descriptions of NASA payloads flown in the 1972

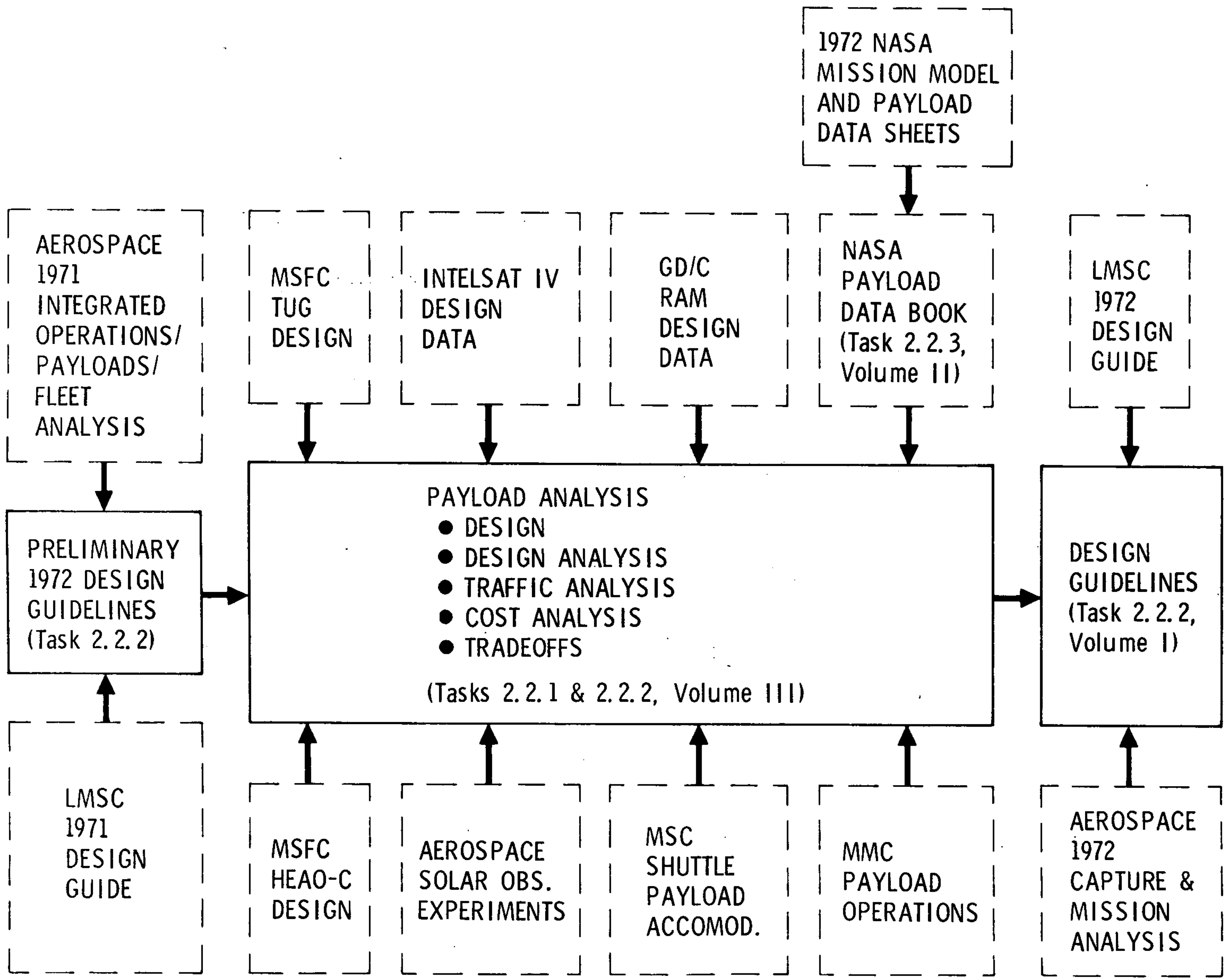

Figure 1. Payload Analysis and Guidelines, Data Flow

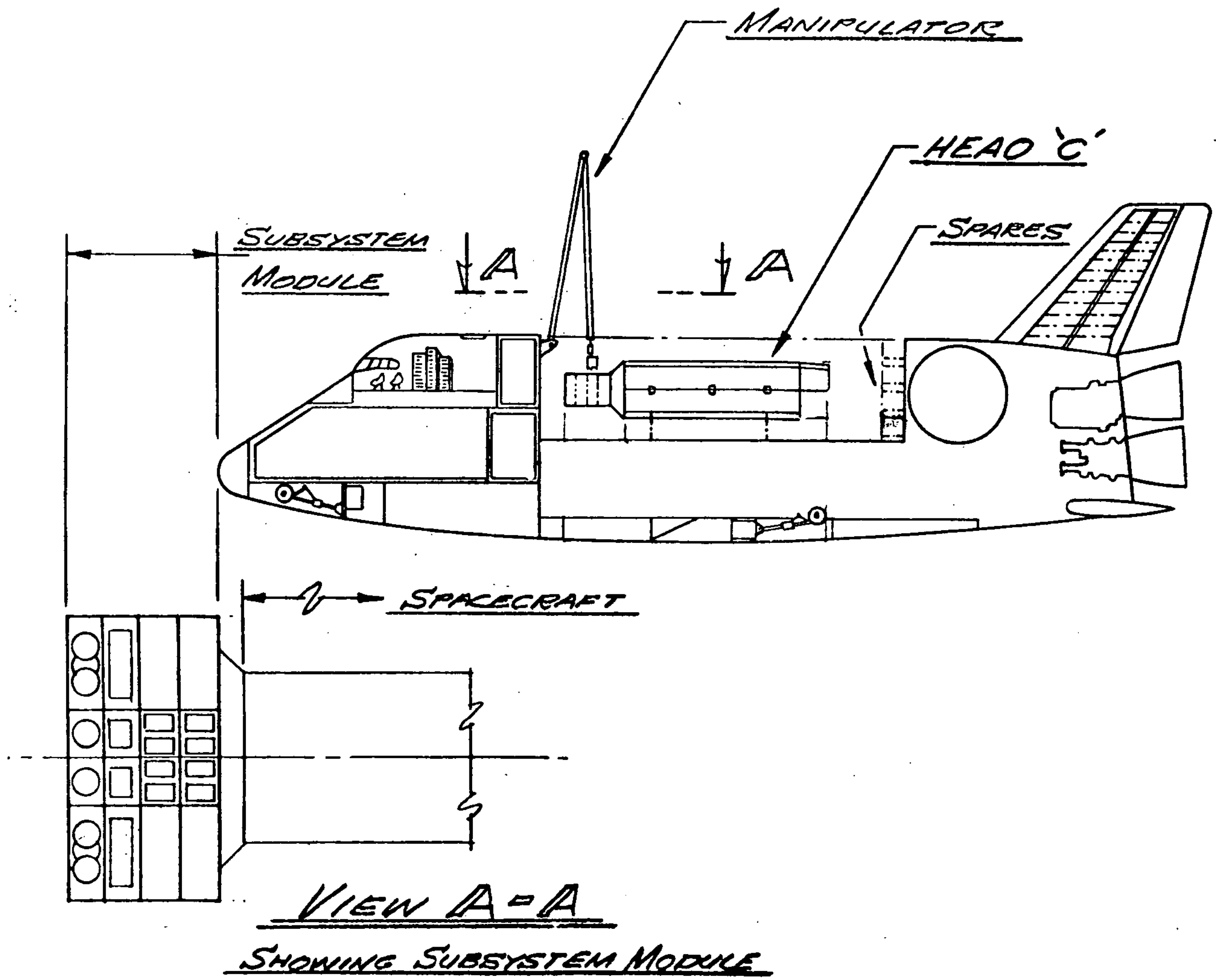

Figure 2. Revisitable HEAO Design, Serviced by Automated Device

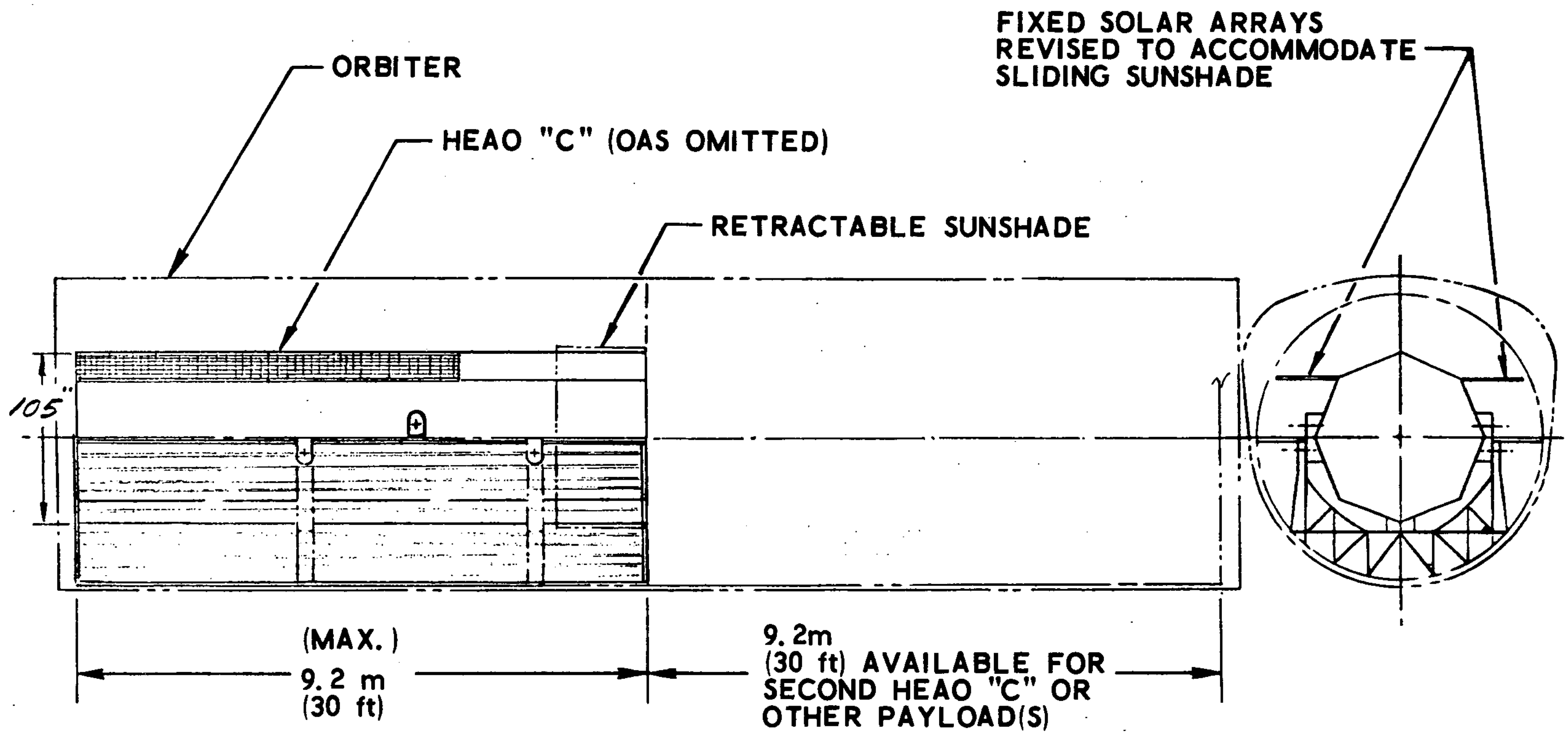

Figure 3. Modified HEAO-B Design, Ground Refurbishable

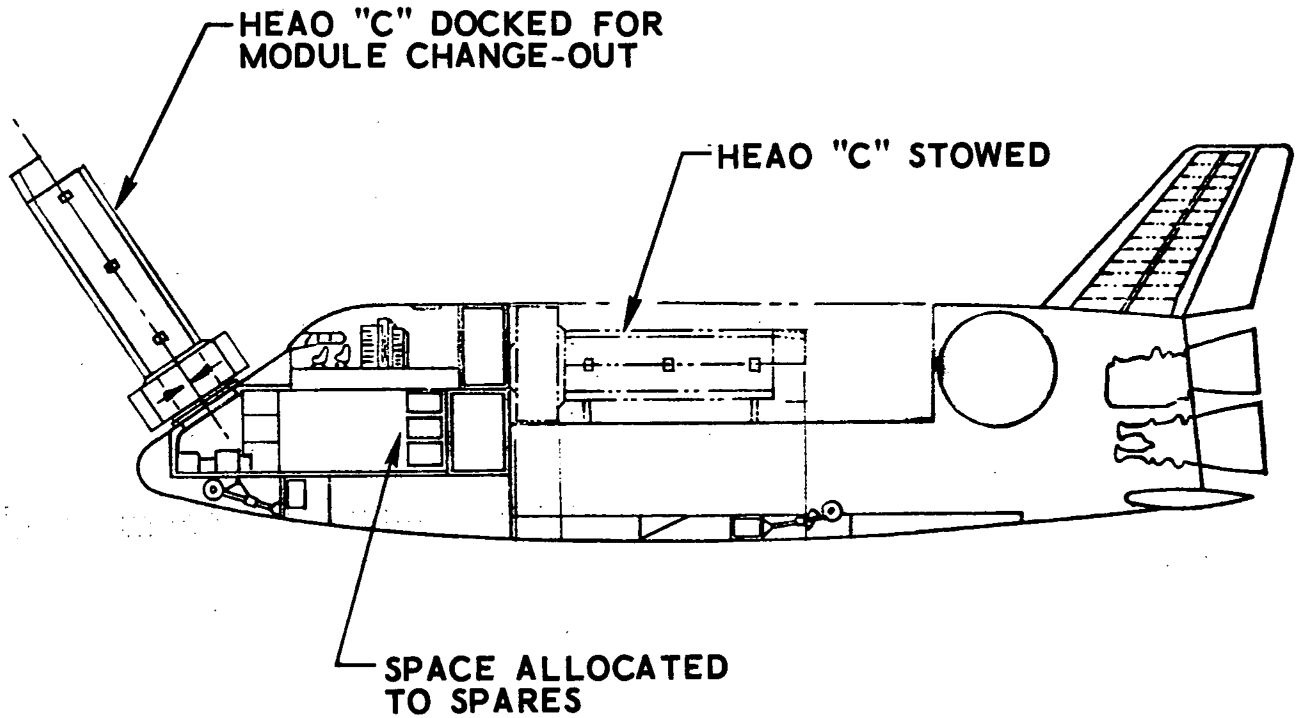

Figure 4. Man-Tended HEAO Design

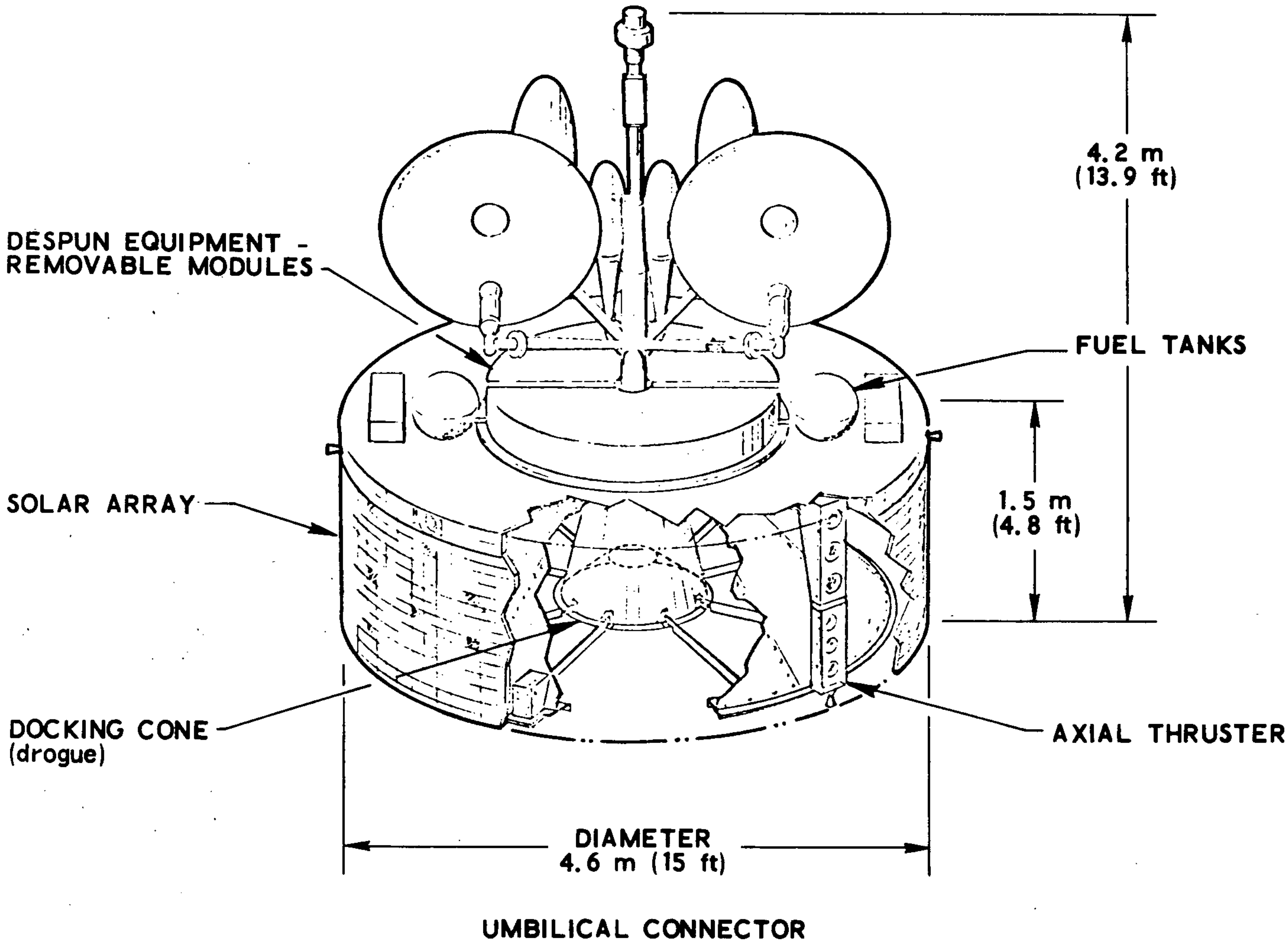

Figure 5. Shuttle-Optimized Reusable Communications Satellite

NASA mission model were furnished by NASA. The information was supplemented using the satellite design data bank and the subsystem specialists at The Aerospace Corporation. After NASA review, this basic set of consistent information for use in NASA payload studies was published in Volume II.

2. NASA PAYLOAD GUIDELINES

As depicted in Figure 6, the Space Shuttle/Space Tug system has characteristics which influence payload programs, their modes of operation, and cost. The intact abort capability will reduce to nearly zero the number of payloads lost during launch. The round-trip capability will reduce to a negligible number payloads lost due to infant mortality. The round-trip capability will also enable satellites suffering random failures or component wearout to be retrieved for repair or refurbishment, or to be maintained on orbit with return of high-value modules.

The interface between the payload and the Shuttle orbiter or the payload and Tug will be the same for nearly all payloads. In effect this standardizes the payload interface with the launch vehicle and leads directly to the opportunity for payload interface hardware commonality on the payload side. In addition, the launch vehicle environment will be the same for all payloads, making it unnecessary to requalify payload hardware for launch environment, which is another reason for equipment commonality.

The launch facility area will be smaller than today. Therefore, centralized payload handling and repair will result and it may be possible to use much of the same AGE for the payloads.

Taken as a whole, these cooperative Shuttle/system effects have a synergistic effect which should result in new satellite systems with lower total and peak costs than today's programs. Payload hardware will be inherited from one payload program to the next and satellite hardware operation can be extended with repair and refurbishment.

It is proposed that the step-by-step procedures developed in this study and described in Volume I be implemented for each Shuttle payload. These Shuttle payload definition studies (as outlined by the procedures) are required in order to realize the benefits for Shuttle payloads

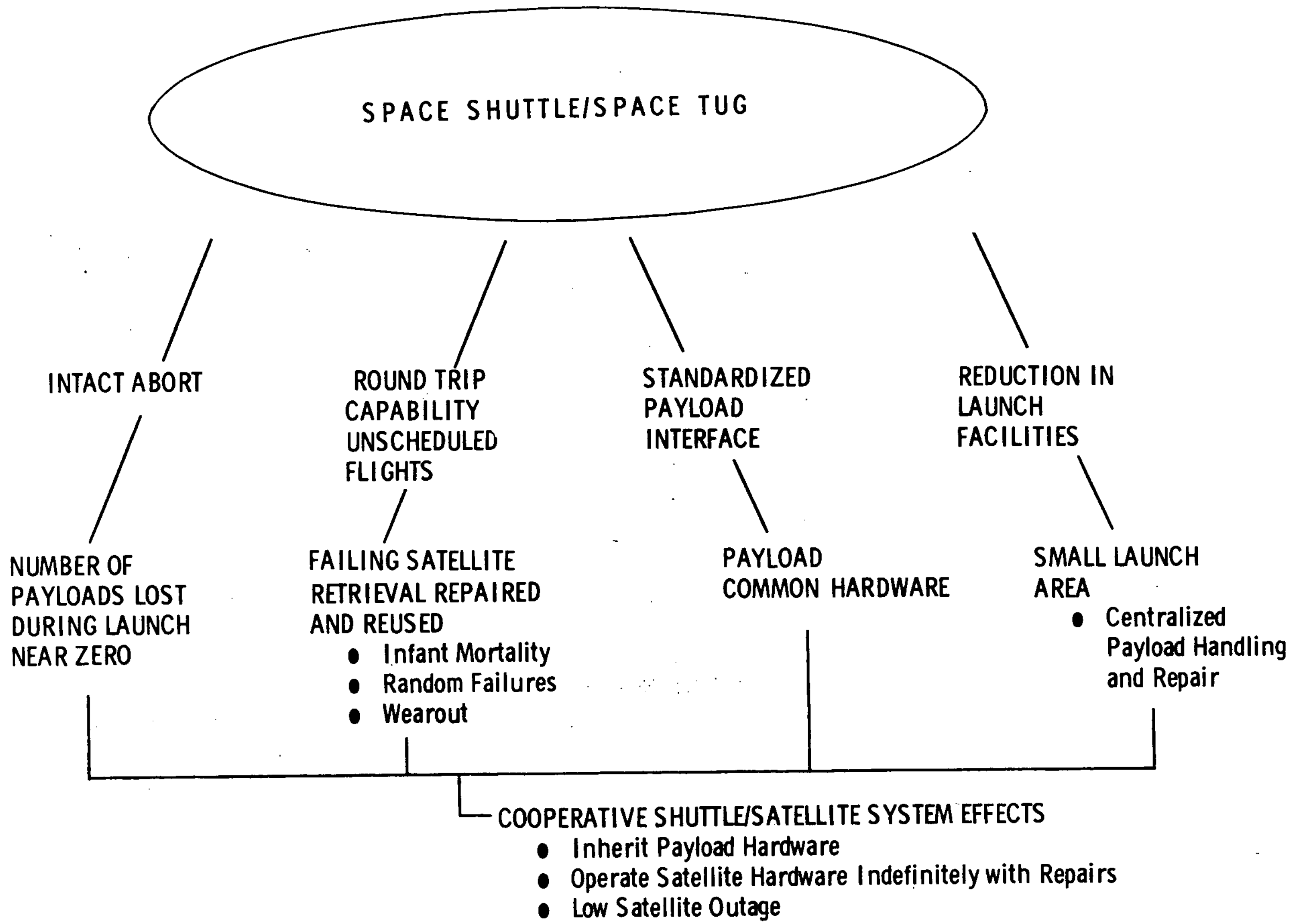

Figure 6. Potential Satellite System Characteristics

found in LMSC's Payloads Effects Analyses, Aerospace's Integrated Operations/Payloads/Fleet Analysis, and Mathematica's Economic Analysis for New Launch Vehicles.

These recommended payload definition studies are designed so that mission objectives and mission equipments are defined as the initial step and kept constant throughout the payload definition study. The end product of the recommended procedures is the satellite system definition and satellite design, specifications, and funding requirements. The resulting satellite design will be optimized for the Shuttle instead of for expendable launch vehicles. (See Figure 7.)

It is recommended that OSS and OA require payload studies to implement the procedures and guidelines for all NASA Shuttle-supported payload studies. The procedures and guidelines have been constructed for this purpose (see Volume I). As a result NASA will obtain payload definitions suitable for phasing into the Shuttle era with reduced cost payload systems. The NASA payload study efforts by the NASA payload program offices can be directed toward the common NASA goal of implementing payload program cost savings available with the Shuttle system.

Study 2.2 is primarily concerned with the NASA payloads associated with the Shuttle in the period 1978 through 1982. This is sometimes called the transition period, which is expected to be the period of most interest for OSS and OA in defining the Shuttle payloads in the next two or three years. Additional effort is recommended to study the guidelines and payload requirements for the fully operational Shuttle and Tug era, 1983 on.

The implementation of the recommended definition studies includes mission equipment, spacecraft, ground station, launch site, Space Shuttle, upper stage, and programmatic considerations. One approach to NASA technical management of the definition studies recommend herein would be to coordinate the work by means of documenting the best available information and data from each of the above areas for analysis.

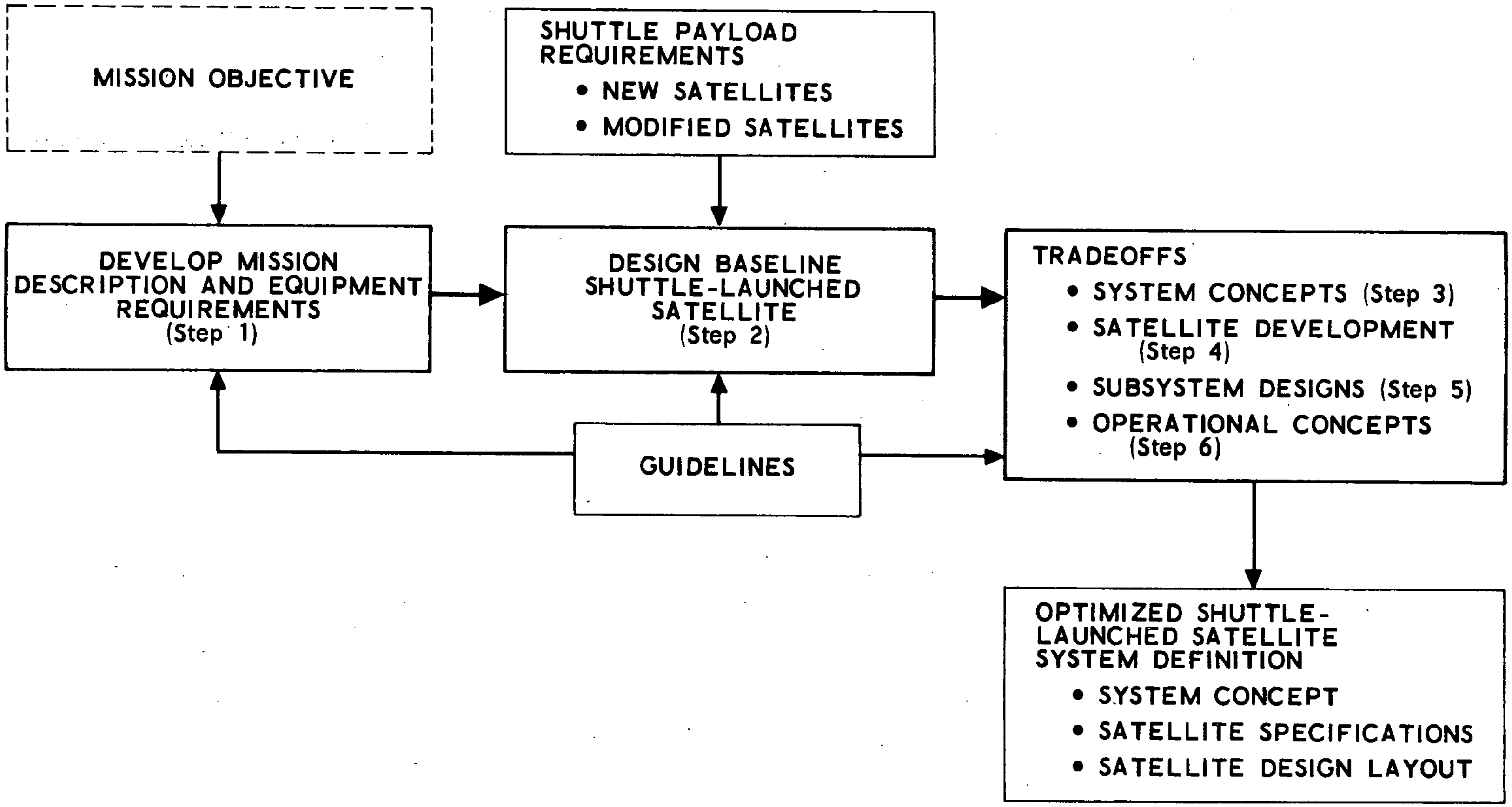

Figure 7. Recommended Procedures, Shuttle Payload Definitions

Specifically, the Shuttle program documents requirements and payload accommodation information. It is assumed that the information will be updated and supplemented and operations information formalized. It is assumed that Shuttle upper stage information will be similarly documented and made available to payload programs. In addition it is recommended that each payload program document payload requirements, payload subsystem assembly or module commonality (with other payloads), the potential of subsystem modules for standardization, Shuttle system interface and service requirements, and payload operational requirements for all phases of payload operations. These documents will be needed by NASA in order to carry on the payload system definition and tradeoff studies.

It is estimated that the minimum elapsed time for accomplishing the definition of a Shuttle-optimized payload is 24 months if NASA elects to accomplish the tradeoff studies on a concurrent basis.

To help the reader visualize the expected gross effects of these procedures and guidelines on NASA satellite programs, cost estimates were made and the criteria described in Volume I were applied to each program. It was assumed that Tug retrieval will be available shortly after 1982. It was also assumed that on-orbit maintenance by the Tug would be accomplished somewhat later than retrieval. The results are shown in Table 1. Of the 20 automated satellite programs in the June 1972 NASA mission model operating in the 1979 through 1982 time period, nine spacecraft would be modified for the Shuttle from expendable designs; 11 spacecraft would be new designs for Shuttle launch. Most of the satellites are either ground refurbishable or expendable. It is economical to configure the LST for on-orbit maintenance. If the earth resources satellite phases directly into the non-NASA mission model, it too would be maintained on orbit by the Shuttle.

Table 1. NASA Shuttle Satellites, 1972 Mission Model – Estimates for Baseline Satellite Types, 1979-1982 Launches (Payload Data from Volume II)

Satellite Program			First Launch In Model	Spacecraft Spaceframe for Shuttle		Upper Stage		Satellite Type			Large/Low Cost Effects Apply
				Mod.	New	Yes	No	Expendable	Ground Refurbishable	On-Orbit Maintainable	
OSS											
1	NA2-1	Explorer - LEO, Astronomy	1973	X			X	X			
2	NA2-2	Explorer - Sync Astronomy	1980	X		X		X			
3	NA2-3	HEAO	1975	X			X		X		
4	NA2-5	LST	1979		X		X			X	X
5	NP2-13	Explorer - Upper Atmos Space Physics	1973	X			X		X		
6	NP2-14	Explorer - Med Altitude, Space Physics	1979		X	X		X			X
7	NP2-16	Gravity and Relativity, LEO	1979		X		X		X		X
8	NP2-18	Environ. Perturb. Sat - Mission A	1981		X	X			X		X
OA											
9	NE2-38	Earth Observ. Sat	1978		X		X		X		X
10	NE2-39	Sync Earth Observ. Sat	1980		X	X			X		X
11	NE2-40	TIROS	1976	X		X		X			
12	NE2-41	Sync Met Sat	1973	X		X		X			
13	NE2-42	Earth Resources Sat	1979		X		X	No	TBD	TBD	X
14	NE2-45	Geopause	1979		X		X	X			X
15	NC2-46	Applic Tech Sat	1973	X		X			X		
16	NC2-47	Small App. Tech. Sat. Sync	1976	X		X		X			
17	NC2-48	Small App Tech Sat-Polar	1976	X		X		X			
18	NC2-49	Tracking and Data Relay Sat	1977		X	X			X		
19	NC2-50	Disaster Warning Sat	1978		X	X			X		
20	NC2-51	System Test Sats	1980		X	X			X		X
Automated Satellite Totals				9	11	12	8	8	10	1	9
Sortie			1979		X		X			X	X

3. FINDINGS

(1) Savings in satellite development phase costs could be realized by modifying developed spacecraft for follow-on missions in the Shuttle era instead of developing new spacecraft. On the basis of the data from Section 7 Volume III the following example is developed:

EXAMPLE

Program	Reduction in RDT&E Cost (1979-1990)	Cost Driver
HEAO	38 percent	Adapt HEAO-B spaceframe design to HEAO-C rather than developing new HEAO-C spacecraft.
TDRS	45 percent	Adapt satellite design to new communications equipment* rather than developing new spacecraft

*Similar to the Nimbus/ERTS program or Mariner program. With Shuttle payloads designed for flexibility and maintainability, the cost of adapting a spacecraft to new mission equipment is expected to be relatively low in comparison to new spacecraft costs.

(2) To obtain low total development costs and total program costs, the design of new satellites scheduled for launch on the Shuttle should be optimized for the Shuttle even if launched before the Shuttle era. On the basis of data from Section 7 Volume III, the following example is developed:

EXAMPLE

Program	Reduction in Total Program Cost	Cost Driver
TDRS	8 to 26 percent	Shared launch costs and optimized satellite life

(3) For Shuttle-launched satellite programs, the long-range costs as well as the costs for the first block of satellites should be considered in selecting the optimum Shuttle-launched spacecraft for OSS or OA programs. For example:

> Increasing the TDRS costs by $20 million through the 1978 IOC* will provide a net $90 million savings in the total program through 1990 from a Shuttle-optimized, reusable spacecraft. This is a good trade (see Figure 5 for Shuttle-launched satellite).

For example:

> Increasing the HEAO costs through HEAO-C IOC* by $60 million to obtain a revisitable satellite instead of a modified HEAO-B configuration which is refurbished on the ground saves a net of $80 million. This is not a favorable cost trade. (See Figures 2 and 3 for revisitable and ground refurbishable spacecraft.)

(4) Most NASA satellites that are candidates for launches in the Shuttle era are based on existing designs which are optimized for expendable launch vehicles (see Volume II of this report). Shuttle payload definition studies are needed to obtain payload designs optimized for Shuttle launch. The satellite characteristics for Shuttle-optimized payloads will be quite different (shorter, fatter, designed for ease of maintenance, most equipment common between spacecraft, component redundancy optimized for logistics, etc.) so quite different designs will be needed.

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*Initial Operational Capability of the satellite system. For first year of planned operational capability, see 1972 NASA mission model.

An estimate of the NASA payload characteristics has been made using the guidelines for Shuttle payloads as criteria (see Volume I). OSS and OA payloads orbited through 1982, as depicted in the 1972 NASA mission model, are covered. It is estimated that of the 20 automated satellites examined, 12 will be reusable and eight will be expendable configurations (see Table 1). It is the 12 reusable satellites that most need definition as Shuttle-optimized payloads.

(5) It appears to be even more desirable to design and analyze OA demonstration programs, such as earth observations, earth resources, and system test satellites, as NASA programs feeding into non-NASA programs in the Shuttle era. The rationale is: with reusable satellites the non-NASA user is very likely to keep using the same reusable spacecraft (perhaps with modifications and redesigned mission equipment) for many years.

(6) The satellite program cost of a man-tended HEAO design (see Figure 4) does not differ significantly from the cost of a satellite serviced on orbit by an automatic device; the reliability and confidence level, however, may be different.

(7) The optimum spacecraft life for HEAO-C launched and maintained by the Space Shuttle is two years.

(8) For the solar observatory program there are two options identified which have low costs compared to other options. One is the free flying observatory, which is similar to that described in the 1972 NASA mission model. The other option would orbit the same instrument package as the free flyer, but would fly periodically in a sortie mode. The sortie large solar observatory (LSO) is supplemented with an orbiting solar observatory (OSO) program for continuous coverage. The sortie LSO appears to have a potential for lower cost hardware than this study was able to investigate conclusively. Lower cost equipments such as

aircraft parts should be analyzed for use on sortie because of the short duration (seven days) and on-orbit service available from the Shuttle. The sortie LSO should be studied further.

4. BACKGROUND

Study 2.2 was inspired by the results of economic studies for launch vehicles sponsored by NASA in FY 1971 (see Ref. 1). When the economic analysis results are adjusted to account for the $10.5 million launch charge, 65 percent of the annual cost savings for the Shuttle/Tug era compared to expendable launch vehicle-supported space systems is due to payload retrieval and reuse. Payload reuse was established as a driver in lowering payload costs. The data also established the predominance of payload RDT&E in the remaining direct costs for a Shuttle payload program. Thus the emphasis in this study is in these two areas.

It is estimated that the Space Shuttle with the best payload mix will save an average of $1.02 billion per year for the non-military users, and $0.39 billion for DoD users. The total of $1.05 billion per year savings does not include the potential savings for the DoD support mission payload effects. The cost savings will be attributable to:

	Percent of Savings	$B Savings
Lower Launch Costs	24.0	0.25
Increased Launch Vehicle Reliability	4.0	0.04
Payload Retrieval and Reuse	65.0	0.69
Low Cost Payload Design	7.0	0.07
	100.0	1.05

The savings due to lower launch costs were calculated for the partially reusable Shuttle at $10.5 million per launch. Therefore the data in the table have changed from Ref. 1 which considered the fully reusable Shuttle at $4.4 million per launch.

The $2 billion per year average direct costs for all users in the Space Shuttle era will be attributable to:

	Percent of Direct Costs	Yearly $B Costs
Payload RDT&E	27.5	0.65
Payload Investment	14.5	0.34
Payload Operations and Refurbishment	30.0	0.71
Launch Costs ($10.5 M/launch)	28.0	0.66
	100.0	2.36

Of this $2 billion per year, $1.3 billion is the estimated NASA direct cost. An average of $950 million per year is estimated for NASA automated spacecraft programs.

The value to the national space program of the reusable Space Tug with satellite retrieval capability was estimated. Once the Tug is fully operational, its use reduces the average yearly direct costs by approximately $500 million compared to the alternative of flying expendable Agena and Centaur upper stages on the Space Shuttle fleet.

5. RECOMMENDATIONS ON SHUTTLE SERVICES AND INTERFACES

During the study effort the orbiter/payload interface area was examined with respect to integrating the payload to the Shuttle/Tug. As a result the following recommendations are made on Shuttle services and payload interfaces:

a. The orbiter manipulator should include the on-orbit capability to remove and replace payload modules, and to operate levers and knobs of serviceable payloads when they are secured to the Shuttle. (See section 6.3.2 Volume III.)

b. The orbiter should include the capability to reject at least 4 kW of payload heat during on-orbit sortie operations. Ref. 2 has not specified the on-orbit coast heat rejection capability. (See section 4.4.5 Volume III.)

c. In the Shuttle era the payload subsystems and components should include equipments which are common with other payloads. Commonality and standardization of equipments should be encouraged by standardizing power supply at 28 volts DC, standardizing satellite data bus formats, and continuing with standard on-orbit-to-ground links. Standardization of satellite test procedures at the factory, launch site, and on orbit are recommended. The payload, ground support equipment, and Shuttle should all have common interfaces with the payload. (See section 2.6 Volume III.)

d. For the sortie missions, long duration orbiter reaction control is required. According to the Shuttle Level 1 document, the orbiter reaction control system is capable of "pointing exposed payload continuously for one orbit every other orbit for one 24-hour period per mission at any ground, celestial, or orbital object within ± 0.5 degrees." This limitation should be modified to provide longer duration pointing capability by possibly assessing the payload for requiring longer than 12 hours per mission. The analysis (see section 4.5.2 Volume III) for solar observation shows a need for 5 1/2 days of orbiter reaction control for payload purposes, 12 hours duration per day. The payload bay is shared with other experiments which may also require reaction control during the 7-day period, possibly extending the period to six or seven days. Further study is recommended to trade-off the sortie mode requirements against the orbiter reaction control duration for payloads beyond the 5 1/2-day period.

6. REFERENCES

1. Integrated Operations/Payloads/Fleet Analysis Final Report, Volumes I through V, ATR-72(7231)-1, The Aerospace Corporation (August 1971).

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3. Space Shuttle Program Requirements Document - Level I, Revision No. 4, NASA/OMSF (21 April 1972).

4. Baseline Tug Definition Document, Revision A, NASA/MSFC (26 June 1972).